Diagnostics and Control of Natural Gas-Fired Furnaces via Flame Image Analysis

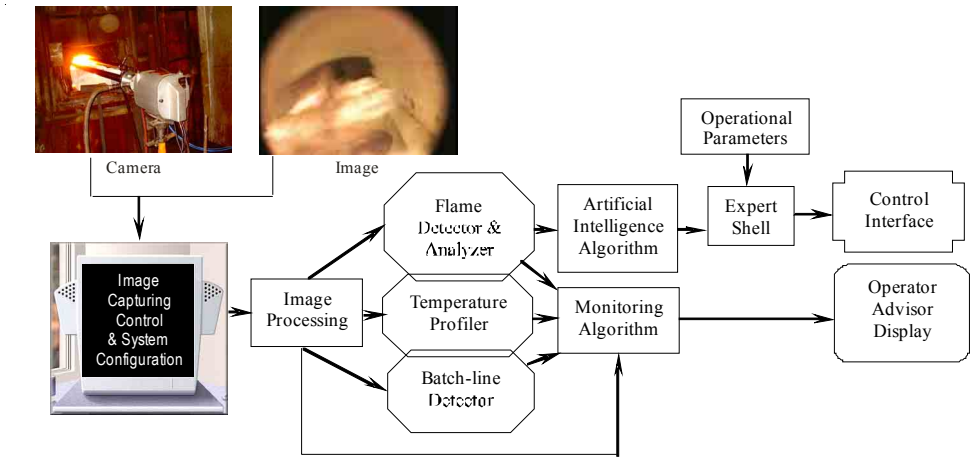
Video Images and Artificial Intelligence Offer Improved Control of Furnaces

The University of Missouri-Columbia (UMC) has developed a novel approach for controlling gas-fired furnaces based on the detection of real-time properties of flames. With support from the U.S. Department of Energy, UMC has created an expert system that employs video images and artificial intelligence to measure flame characteristics, temperature, and melt separation during production. The on-line furnace diagnostic and control system is the first of its kind.

The new flame monitoring expert system uses progressive cameras along with artificial intelligence techniques to identify flame features that can be correlated with air/fuel ratio, NOx emission levels, and temperature. Its 3D temperature profiler enables close control of furnace and flame temperature, key to achieving high product quality as well as reduced NOx emissions. The system also provides guidance for balancing air/fuel ratios between individual burners on multi-burner furnaces. Manufacturers now have a powerful new tool for combustion control costing less than $50,000.

The improved burner balancing and controlled combustion made possible by on-line control help address ever-increasing demands for higher furnace thermal efficiency, reduced NOx emissions, and improved product quality. The new system can provide real-time control of natural gas-fired furnaces in the glass and aluminum industries, as well as reheating furnaces used in steel and forging industries.

Flame/Furnace Image Analyzer



Benefits for Our Industries and Our Nation

Improved burner balancing and improved combustion control via flame monitoring allows furnace operation at reduced excess air levels, resulting in improved system efficiency, reduced fuel consumption, and lower NOx emissions. Greater temperature control and uniformity will also improve product quality. For a large gas-fired boiler (5 x 10^9 Btu/hr), a 10-percent reduction in NOx emissions yields savings of $1 million per year from NOx credits alone.

Applications in Our Nation's Industries

The new flame monitoring and analysis expert system offers real-time process control for multi-burner natural gas-fired furnaces throughout industry:

- Glass melting
- Aluminum scrap melting
- Steel reheat furnaces
- Forging furnaces
- reheat furnaces

The system may also be applicable in pulverized-coal combustion systems used in power generation.

Project Summary

Objective:

The project objective was to develop a new method for extracting features from flame images in a gas-fired furnace that can be correlated with combustion parameters such as air/fuel ratio, NOx and CO emissions, and flame temperature. This information can be used to operate the furnace more efficiently.

Technology:

The camera images used by the new expert system come from a periscope-based camera with a water cooling system that enables it to withstand temperatures up to 3500°F. Advanced information processing techniques, including image analysis and artificial intelligence, behave as "virtual sensors" to extract information from the images of the flames. These "sensing" functions — flame monitoring, 3D temperature profiling, and batch-line detection (for glass melting applications) – enable better control of gas-fired furnaces.

The flame monitoring function incorporates a virtual flame detector to identify non-firing burners, a flame monitor with adjustable memory, and a flame analyzer to determine the combustion status of each burner. This sensing function can provide guidance for balancing air-fuel ratios between individual burners in multi-burner furnaces with individual burner control capability.

The temperature profiler provides pseudo three-dimensional color temperatures of flames and the furnace walls and crown for better temperature control. The batch-line detector, specifically designed for use in glass melting furnaces, clearly identifies the location of the boundary between the feed and the melt

The flame monitoring system as a whole can be integrated into a furnace control system operating in real time or can be utilized as a diagnostic tool for manual control adjustment. In either case, the system represents a low-cost retrofit option for implementing advanced process control.

Project Milestones:

This project was awarded in January 2000 through a FY 2000 solicitation by the Sensors and Controls Program. Key tasks performed were:

- Completed Phase I feasibility study February 2001. Major tasks included data/image acquisition, spectroscopic data analysis and temperature calculation based on black-body radiation model, flame image analysis, and pattern recognition using adaptive resonance theory neural networks.
- Completed Phase II December 2003. Major tasks included design and fabrication of water/air-cooled case and off-line control experimentation at commercial glass furnaces for both oxy/fuel and air/fuel burner operation.

Commercialization:

The final product capabilities emerging from this project have exceeded original expectations. Pilot-scale testing and performance evaluation of the expert system in a commercial furnace is completed.

For More Information

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